

# Dark matter in a SUSY left-right model

**A. Vicente**

Laboratoire de Physique Théorique, CNRS – UMR 8627, Université de Paris-Sud 11, F-91405 Orsay Cedex, France

E-mail: [Avelino.Vicente@th.u-psud.fr](mailto:Avelino.Vicente@th.u-psud.fr)

**Abstract.** Supersymmetric left-right models are well motivated extensions of the Minimal Supersymmetric Standard Model since they automatically contain the ingredients to explain the observed neutrino masses and mixings. Here we study a SUSY model in which the left-right symmetry is broken by triplets at a high scale leading to automatic R-parity conservation at low energies. The sparticle spectra in this model differ from the usual constrained MSSM expectations and these changes affect the relic abundance of the lightest neutralino. We discuss two examples: (1) the standard stau co-annihilation region, and (2) flavoured co-annihilation.

## 1. Introduction

There are good theoretical and phenomenological reasons to consider left-right (LR) extensions [1, 2, 3] of the MSSM. Besides the restoration of parity at high energies, two motivations can be especially highlighted. First, LR models contain all the ingredients to explain the observed neutrino masses and mixings thanks to the well-known seesaw mechanism [4, 5, 6, 7]. And second, the gauging of  $B - L$  provides a natural framework to explain the origin of R-parity, which can be understood as the low energy remnant of the high energy gauge symmetry.

Here we will concentrate on the LR model proposed in [8, 9]. The main difference with respect to previous proposals [5, 10, 11] was the presence of additional triplets with zero  $B - L$  charge. The main advantage of this setup, in the following called the  $\Omega$ LR model, is the existence of R-parity conserving minima in the tree level scalar potential.

In the  $\Omega$ LR model [8, 9] new superfields appear with masses below the GUT scale. Furthermore, the gauge group is extended to  $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$  at energies above the LR breaking scale. Both facts significantly affect the RGE running of all parameters. Therefore, even though the LR breaking scale is very far from the reach of current accelerators, there are interesting effects in the phenomenology caused by the running of the soft supersymmetry breaking parameters and the subsequent deformation of the SUSY spectra with respect to the CMSSM expectation [12, 13].

Astrophysical observations and the data from WMAP [14] put on solid grounds the existence of non-baryonic dark matter in the universe. The most popular candidate is the lightest neutralino in R-parity conserving supersymmetry. However, all solutions in the CMSSM parameter space [15] require a fine-tuning [16] among some masses in order to enhance the annihilation/co-annihilation cross-sections, decrease the lightest neutralino relic abundance,  $\Omega_{\tilde{\chi}_1^0} h^2$ , and reproduce the observed dark matter relic density [14]. Therefore, it is not surprising that even small changes in the SUSY spectra can dramatically change the resulting  $\Omega_{\tilde{\chi}_1^0} h^2$ . The description of these changes in the  $\Omega$ LR model is the main subject of this work.

## 2. The model

In this section we present the model originally defined in [8, 9]. For further details see [12, 13].

Below the GUT scale the gauge group of the model is  $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ . Besides the particle content of the MSSM with the addition of (three) right-handed neutrino(s)  $\nu^c$ , some additional superfields are introduced. First, two generations of  $\Phi$  superfields, bidoublets under  $SU(2)_L \times SU(2)_R$ , are introduced. Furthermore, triplets under (one of) the  $SU(2)$  gauge groups are added with gauge quantum numbers  $\Delta(1, 3, 1, 2)$ ,  $\Delta^c(1, 1, 3, -2)$ ,  $\bar{\Delta}(1, 3, 1, -2)$ ,  $\bar{\Delta}^c(1, 1, 3, 2)$ ,  $\Omega(1, 3, 1, 0)$  and  $\Omega^c(1, 1, 3, 0)$ .

With these representations and assuming parity conservation, the most general superpotential compatible with the symmetries is

$$\begin{aligned} \mathcal{W} = & Y_Q Q \Phi Q^c + Y_L L \Phi L^c - \frac{\mu}{2} \Phi \Phi + f L \Delta L + f^* L^c \Delta^c L^c + a \Delta \Omega \bar{\Delta} + a^* \Delta^c \Omega^c \bar{\Delta}^c \\ & + \alpha \Omega \Phi \Phi + \alpha^* \Omega^c \Phi \Phi + M_\Delta \Delta \bar{\Delta} + M_\Delta^* \Delta^c \bar{\Delta}^c + M_\Omega \Omega \Omega + M_\Omega^* \Omega^c \Omega^c. \end{aligned} \quad (1)$$

The breaking of the LR gauge group to the MSSM gauge group takes place in two steps:  $SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_R \times U(1)_{B-L} \rightarrow U(1)_Y$ . First, the neutral component of the  $\Omega^c$  triplet takes a VEV (vacuum expectation value),  $\langle \Omega^{c0} \rangle = \frac{v_R}{\sqrt{2}}$ , breaking  $SU(2)_R$ . Next, the group  $U(1)_R \times U(1)_{B-L}$  is broken by  $\langle \Delta^{c0} \rangle = \langle \bar{\Delta}^{c0} \rangle = \frac{v_{BL}}{\sqrt{2}}$ . Neutrino masses are generated at this stage via the superpotential term  $f^* L^c \Delta^c L^c$  which, after  $U(1)_{B-L}$  gets broken, leads to Majorana masses for the right-handed neutrinos and a type-I seesaw mechanism.

## 3. Low energy spectrum and dark matter

In general, with  $v_{BL} \leq v_R < m_{GUT}$ , the  $\Omega$ LR has a lighter spectrum than the CMSSM for the same parameters. Since in the  $\Omega$ LR model the running of the gauge couplings is changed with respect to the MSSM case, also gaugino masses are changed. Consider for example  $M_1$ . At 1-loop leading-log order we find

$$M_1(m_{SUSY}) = M_{1/2} [X_1 + X_2 (-3l_1 + l_2)] \quad (2)$$

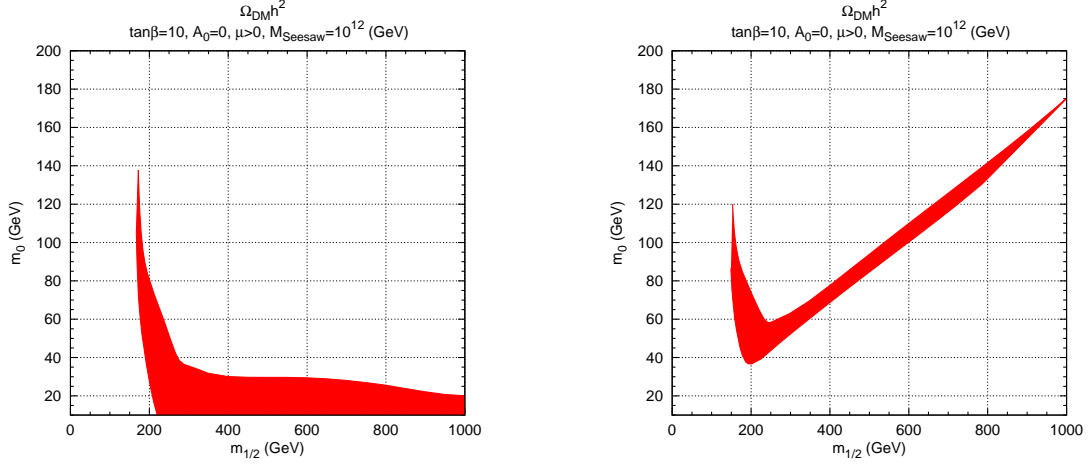
where  $l_1 = \ln\left(\frac{m_{GUT}}{v_R}\right)$ ,  $l_2 = \ln\left(\frac{v_R}{v_{BL}}\right)$  and  $X_{1,2} > 0$  are two numerical factors. Equation (2) shows that one can decrease  $M_1(m_{SUSY})$  with respect to the CMSSM value by using a large  $l_1$  and  $l_2 = 0$  and increase it only in the case  $l_2 > 3l_1$ . This change in  $M_1(m_{SUSY})$  has a strong impact on dark matter phenomenology, since the lightest neutralino is mostly bino in most parts of parameter space.

We present now our results concerning dark matter phenomenology in the  $\Omega$ LR model. We will discuss the main differences with respect to the CMSSM for (1) the standard stau co-annihilation region [17], and (2) flavoured co-annihilation [18]. The numerical evaluation of the parameters at the SUSY scale was done with **SPheno** [19, 20, 21], using the complete 2-loop RGEs at all scales. These were derived with the Mathematica package **SARAH** [22, 23, 24]. Finally, we used **micrOmegas** [26] to obtain the value of  $\Omega_{\tilde{\chi}_1^0} h^2$

### 3.1. Stau coannihilation

As discussed, lowering the values of  $v_{BL}$  and  $v_R$  leads in general to a lighter spectrum compared to the pure CMSSM case. Since the mass of the bino decreases faster than the mass of the stau, the quantity  $\Delta_m = m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$ , and thus the neutralino relic abundance, gets increased for low  $v_{BL}$  and  $v_R$ . This can only be compensated by reducing  $m_0$  [13].

Two examples of stau co-annihilation regions are shown in Figure 1. As expected, a shift of the allowed region towards smaller values of  $m_0$  is found. Moreover, the region can disappear for sufficiently low  $v_{BL}$  and  $v_R$ . The observation of a particle spectrum consistent with the CMSSM stau co-annihilation region could thus be turned into lower limits on  $v_{BL}$  and  $v_R$ .



**Figure 1.** Dark Matter  $3\sigma$  allowed regions for  $\tan\beta = 10$ , and  $v_{BL} = v_R = 1.5 \times 10^{15}$  GeV (left) and  $v_{BL} = v_R = 10^{16}$  GeV (right).

### 3.2. Flavoured coannihilation

As shown in [12], the  $\Omega$ LR model allows for large flavour violating effects in the right slepton sector. This implies that the  $\tilde{\tau}_R \simeq \tilde{\tau}_1$  can be made lighter by flavour contributions, leading to co-annihilation with the lightest neutralino in points of parameter space where it would be impossible without flavour effects. Moreover, flavour violating processes become relevant in the determination of the relic density, and they must be taken into account. This is the so-called flavoured co-annihilation mechanism [18].

When searching for such points in parameter space one must take into account the strong limits for  $\text{Br}(\mu \rightarrow e\gamma)$  given by the MEG experiment [25]. A fine-tuning of the parameters is required in order to cancel this observable and, at the same time, reduce the  $\tilde{\tau}_R$  mass sufficiently. Figure 2 shows two examples. On the left panel the cancellation of  $\text{Br}(\mu \rightarrow e\gamma)$  is obtained with  $\delta = \pi$  and  $\theta_{13} = 8^\circ$ , while on the right panel with  $\theta_{13} = 9.5^\circ$ . Note that this occurs for different values of  $m_0$  and  $M_{1/2}$ .

## 4. Conclusions

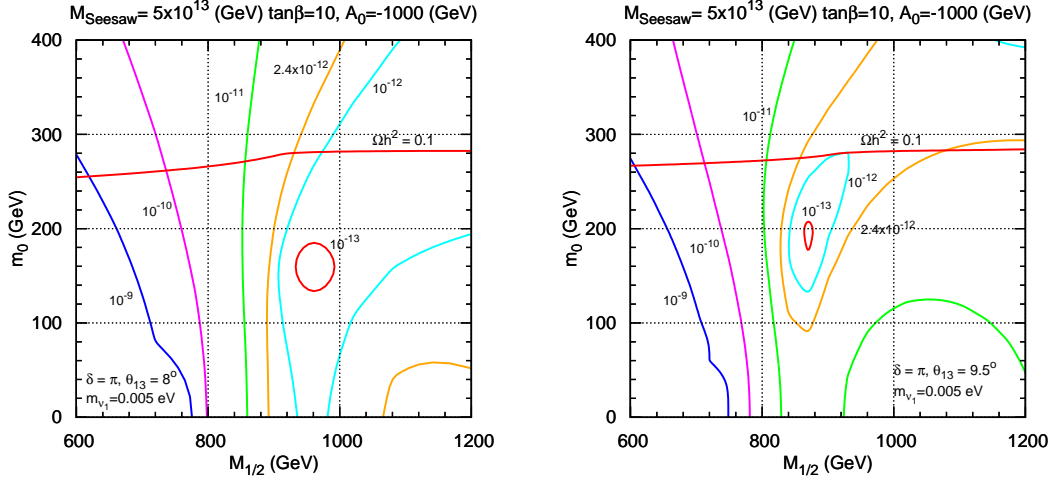
We have studied the dark matter phenomenology of the  $\Omega$ LR model, a supersymmetric left-right model that breaks the LR symmetry at high energies. The change in the running of the parameters at energies above the breaking scale has a strong impact on the low energy spectra, modifying the usual dark matter predictions of the CMSSM.

The shift of the stau co-annihilation region and its potential disappearance has been studied. The fact that the lightest neutralino is usually lighter in the  $\Omega$ LR model than in the CMSSM reduces the allowed stau co-annihilation region, which can even vanish for low  $v_R$  and/or  $v_{BL}$ .

The model also allows for flavoured co-annihilation. Examples have been given of points in parameter space where the  $\tilde{\tau}_R$  mass is reduced by means of flavour effects, leading to the observed dark matter relic abundance.

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**Figure 2.**  $\Omega_{\tilde{\chi}_1^0} h^2$  and  $\text{Br}(\mu \rightarrow e\gamma)$  contour plots in the  $m_0$ - $M_{1/2}$  plane for  $\delta = \pi$ ,  $\theta_{13} = 8^\circ$  (left) and  $\theta_{13} = 9.5^\circ$  (right). Both examples were obtained with  $v_R = 10^{15}$  GeV and  $v_{BL} = 10^{14}$  GeV.

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